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AIRS Absolute Radiometric Accuracy and V6 Improvements

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AIRS Science Team Meeting

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AIRS Has Elements Needed for Climate Benchmark

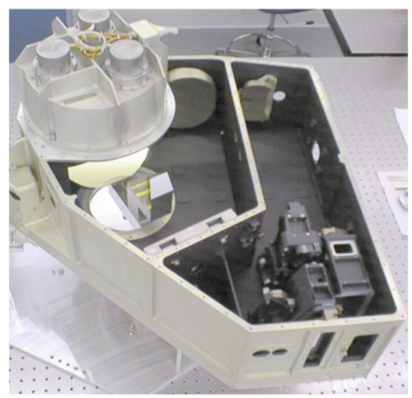
1. High Sensitivity
   – Must have high information content of Earth scene
2. Intensive Pre-flight Calibration
   – Must characterize spatial, spectral, radiometric, polarimetric response
3. High Accuracy
   – Allows for Gaps in Data Record
   – Radiometric Coefficients Traceable to SI Standards
   – Errors Quantified on All Terms in Radiometric Transfer Equations
4. High Stability
   – Must have ability to sense climate signal without ambiguity of instrumental artifacts
5. Good Documentation and Records
   – Future generations should be able to understand and if necessary recreate data record

- **Question: How well are we meeting item 3: High Accuracy?**

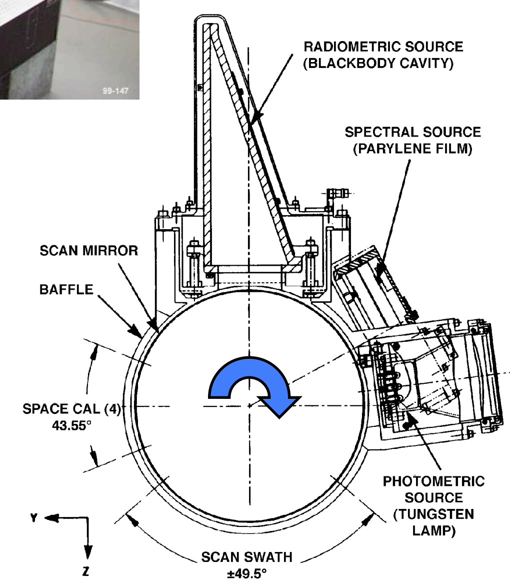
AIRS Designed for High Sensitivity, Accuracy and Stability

AIRS Requirements

- Orbit: 705 km, 1:30pm, Sun Synch
- IFOV : 1.1° x 0.6°
(13.5 km x 7.4 km)
- Scan Range: ±49.5°
- Full Aperture OBC Blackbody, ε>0.998
- Full Aperture Space View
- Solid State Grating Spectrometer
  - IR Spectral Range:
3.74-4.61 μm, 6.2-8.22 μm,
8.8-15.4 μm
  - IR Spectral Resolution:
≈ 1200 (λ/Δλ)
  - # IR Channels: 2378 IR
- Temperature Controlled
Spectrometer: 158K
- Actively Cooled FPAs: 60K
- VIS Channels: 4
- Mass: 177Kg,
Power: 256 Watts,
Life: 5 years (7 years goal)



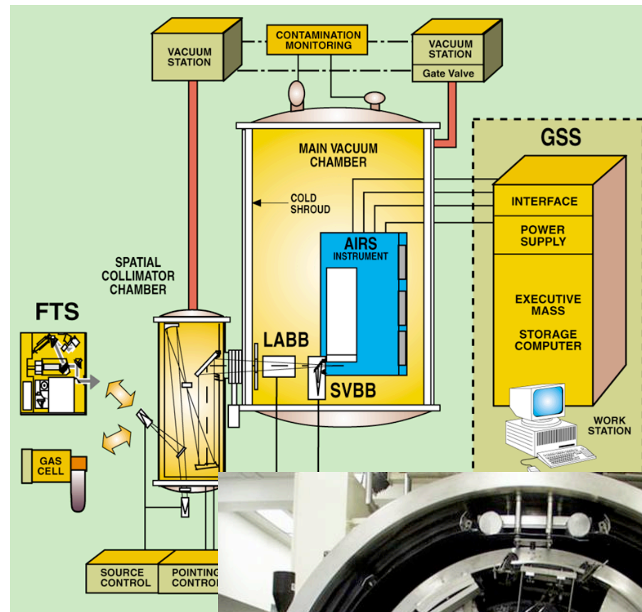
AIRS Spectrometer

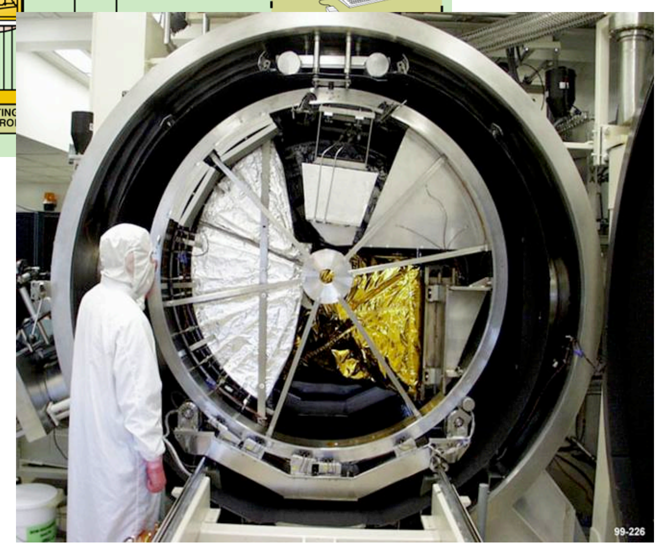


AIRS Scan Cavity

Extensive Pre-flight Calibration on AIRS is Part of Climate Record

- Radiometric Response
  - Emissivity, Nonlinearity
  - Stray Light, Polarization
  - Scan Angle Dependence in TVAC
  - Transfer to On-Board Blackbody
  - 2 TVAC Cycles
- Spectral Response
  - SRF Characterization with FTS
  - Channel Spectra Characterized
- Spatial Response
  - Top-hat Functions All Channels
  - Stray Light Excellent
  - Far Field Response Excellent
- Good Documentation
  - Over 400 Design File Memos





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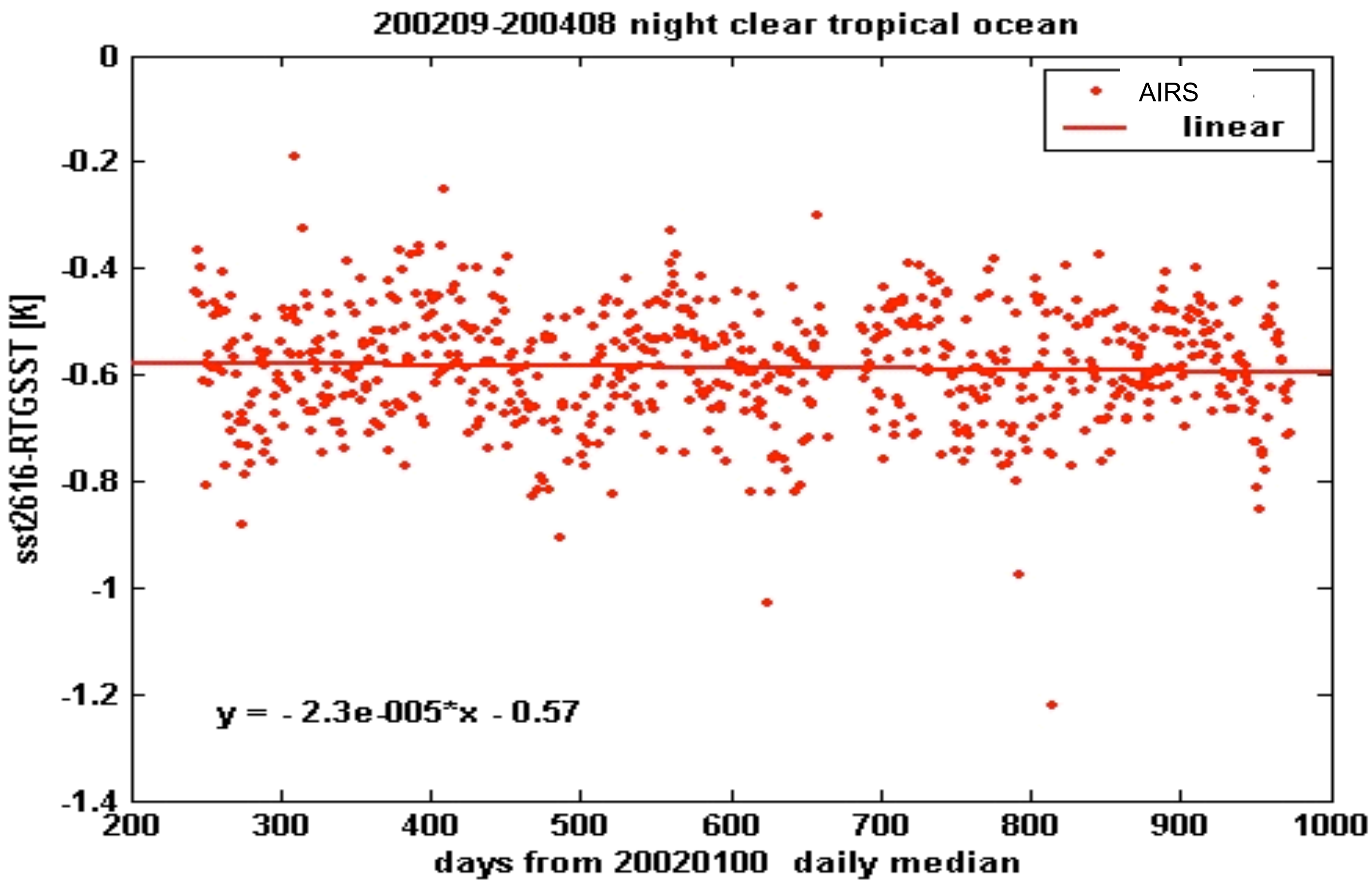
High AIRS stability seen in orbit when compared to Buoys

RTGSST Validates Radiometric Stability <10mK/Y – H. Aumann (JPL)



RTGSST = ***Real-Time Global (RTG) SST analyses. NOAA Reynolds SST***

Reference: JGR, VOL. 111, April 2006

Good Documentation and Records

- All Archives Resident at the AIRS Project Office
  - Instrument Drawings
  - Test Data
  - Test Logs
  - Analysis Software
  - Technical Memos, User Guides and Reports
  - Most Data
- Archives at GES/DISC
  - Data
  - Readers
  - User Guides
- Not yet resolved
  - Where will we put this information so someone can retrieve it 10-100 years from now?
  - Plan: Collect all essential information and readers in single archive location at JPL

Radiometric Accuracy derived from Radiometric Transfer Equations

Radiometric Transfer Equations

$$N_{sc,i,j} = \frac{a_o(\theta_j) + a_{1,i}(dn_{i,j} - dn_{sv,i}) + a_2(dn_{i,j} - dn_{sv,i})^2}{1 + p_r p_t \cos 2(\theta_j - \delta)}$$

$$a_o(\theta_j) = P_{sm} p_r p_t [\cos 2(\theta_j - \delta) + \cos 2\delta]$$

$$a_{1,i} = \frac{N_{OBC,i}(1 + p_r p_t \cos 2\delta) - a_o(\theta_{OBC}) - a_2(dn_{obc,i} - dn_{sv,i})^2}{(dn_{obc,i} - dn_{sv,i})}$$

$N_{sc,i,j}$ = Scene Radiance (mW/m^2-sr-cm^{-1})
Psm = Planck radiation function
$N_{OBC,i}$ = Radiance of the On-Board Calibrator Blackbody
i = Scan Index, j = Footprint Index
θ = Scan Angle. θ = 0 is nadir.

dni,j = Raw Digital Number in the Earth View
dnsv,i = Space view counts offset.
ao = Radiometric offset. a1,i = Radiometric gain.
a2 = Nonlinearity
prpt = Polarization Factor Product
d = Phase of the polarization

T. Pagano et al., “Pre-Launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS),” IEEE TGRS, Volume 41, No. 2, February 2003, p. 265

T. Pagano, H. Aumann, K. Overoye, “Level 1B Products from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft", Proc. ITOVS, October 2003

Coefficients Derived from Linearity Test
(NIST Calibrated Temperature Sensors in LABB)

$$N_{LABB} = \varepsilon_{LABB} \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

Radiance of LABB Tied to NIST Temp Sensors

$$\mathrm{N_{LABB}} = \mathrm{c_o}(\theta_\mathrm{j}) + \mathrm{c_{1,i}}(\mathrm{dn_{i,j}} - \mathrm{dn_{sv,i}}) + \mathrm{c_2}(\mathrm{dn_{i,j}} - \mathrm{dn_{sv,i}})^2$$

Fit AIRS to LABB

$$N_{sc,i,j} = \frac{a_o(\theta_j) + a_{1,i}(dn_{i,j} - dn_{sv,i}) + a_2(dn_{i,j} - dn_{sv,i})^2}{1 + p_r p_t \cos 2(\theta_j - \delta)}$$

Equate Fit to Rad X-Fer Equations

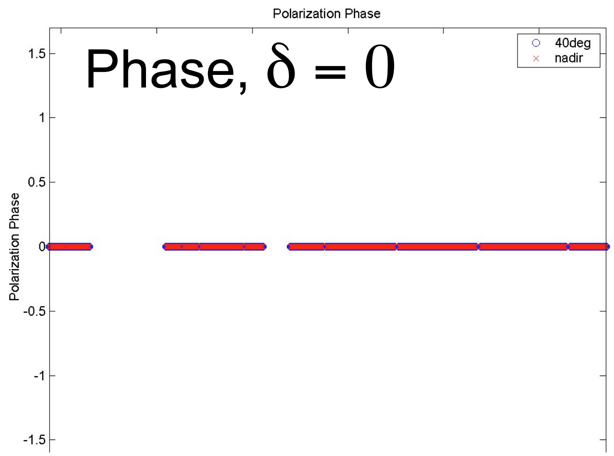
$$\mathrm{p_r p_t} = \frac{\mathrm{c}_o}{\mathrm{P_{sm}}[\cos 2(\theta_\mathrm{j} - \delta) + \cos 2\delta] - c_\mathrm{o} \cos 2(\theta_\mathrm{j} - \delta)}$$

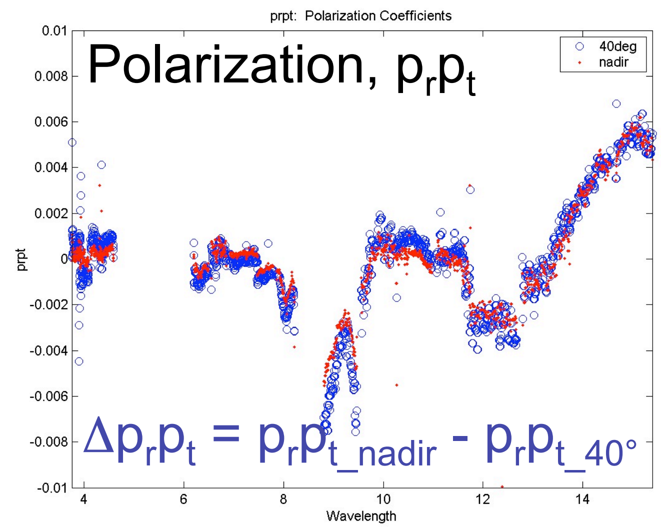
Solve for Coefficients of Rad X-Fer Equations

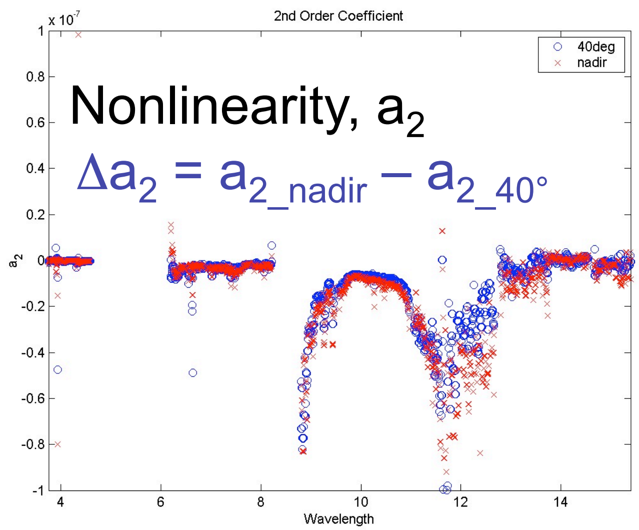
$$\varepsilon_{\mathrm{OBC}} = \frac{2\mathrm{P_{sm} p_r p_t} \cos 2\delta + \mathrm{c_1}\big(1 + \mathrm{p_r p_t} \cos 2(\theta_\mathrm{j} - \delta)\big)(\mathrm{dn_{obc,i}} - \mathrm{dn_{sv,i}}) + \mathrm{c_2}\big(1 + \mathrm{p_r p_t} \cos 2(\theta_\mathrm{j} - \delta)\big)(\mathrm{dn_{obc,i}} - \mathrm{dn_{sv,i}})^2}{\mathrm{P_{OBC,i}}(1 + \mathrm{p_r p_t} \cos 2\delta)}$$

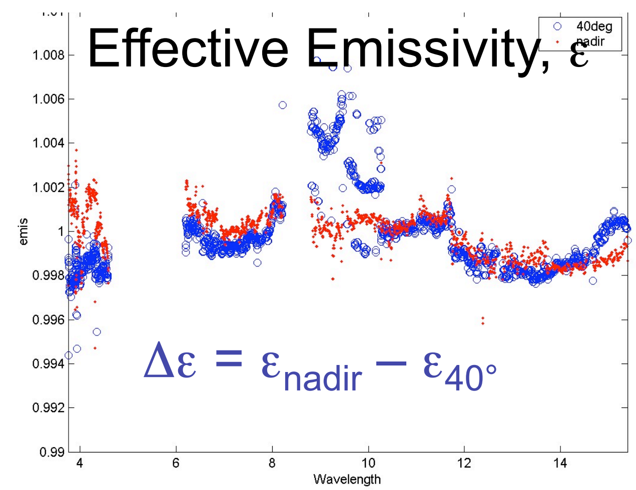
$$\mathrm{a_2} = \mathrm{c_2}\big(1 + \mathrm{p_r p_t} \cos 2(\theta_\mathrm{j} - \delta)\big)$$

Version 6 Calibration Coefficients









- **All Flight Coefficients Based on Nadir Data**
- **Uncertainties Derived from Difference of Nadir and 40 deg**

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Radiometric Accuracy Elements

- *Differentiate radiometric transfer equation to get uncertainties*

$$\partial N_{SC}^{2} = \left(\frac{\partial N_{SC}}{\partial p_r p_t}\Delta p_r p_t\right)^2 + \left(\frac{\partial N_{SC}}{\partial T_{sm}}\Delta T_{sm}\right)^2 + \left(\frac{\partial N_{SC}}{\partial \theta}\Delta \theta\right)^2 + \left(\frac{\partial N_{SC}}{\partial \varepsilon_{OBC}}\Delta \varepsilon_{OBC}\right)^2 + \left(\frac{\partial N_{SC}}{\partial T_{OBC}}\Delta T_{OBC}\right)^2 + \left(\frac{\partial N_{SC}}{\partial a_2}\Delta a_2\right)^2 + \left(\frac{\partial N_{SC}}{\partial dn}\Delta dn\right)^2$$

- *Calculate by Channel. Module Averages Given Below*

Parameter	Uncertainty	Error (K)
Polarization Factors Uncertainty	4.13E-04	0.016
Scan Mirror Temperature Uncertainty	5 K	0.005
Scan Mirror Angle Uncertainty	0 deg	0.000
OBC BB Emissivity Uncertainty	4.26E-04	0.023
OBC BB Temperature Uncertainty	0.03 K	0.022
Nonlinearity Uncertainty	5.9903E-10 Rad/dn^2	0.015
Low Frequency Drift within Scan	0.01 dn	0.006
LABB Temperature Uncertainty	0.03 K	0.030
LABB Emissivity Uncertainty	0.0001 -	0.004
Spectrometer Phase Uncertainty	5 deg	0.000
OBC BB Emissivity End of Life	0.0002	0.008
OBC BB Reflected Energy Uncertainty	7.40E-04	0.027
Gain Drift	4.8258E-06 Rad/dn	0.000
RSS Radiometric Error		0.058

Overall Instrument Average < 60 mK, 1 Sigma?

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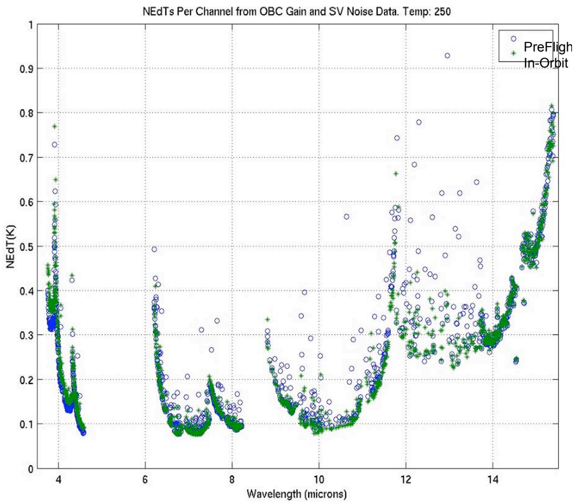
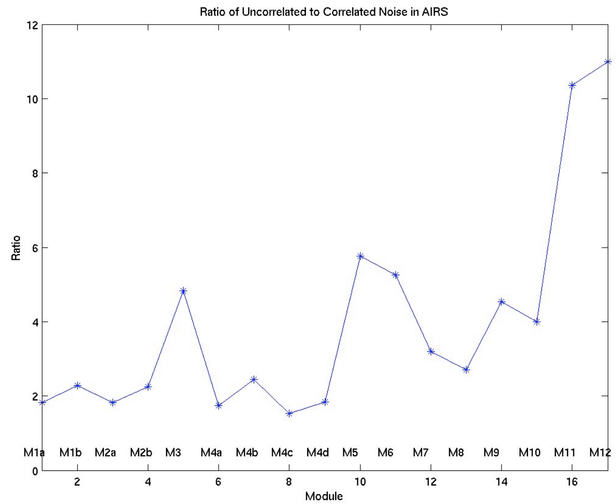
Not included in this Accuracy Prediction

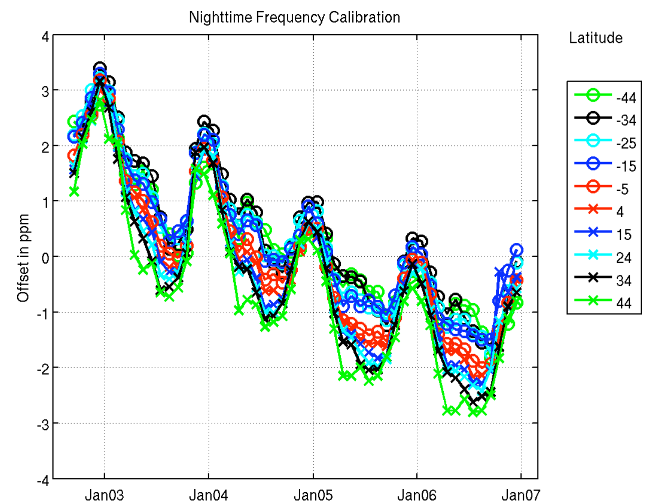
Random Noise



Correlated Noise



Spectral Uncertainty



Random noise is averaged out when obtaining climate signals but must be included when estimating individual sample uncertainty

Correlated noise must be included separately because accuracy will depend on the combination of channels used

Spectral uncertainty is a scene dependent error and must be included separately in science climate accuracy estimates

Assumptions for Uncertainty

- All coefficient terms traceable to LABB calibration. Theoretical bias uncertainty related to bias uncertainty of LABB
- Residual uncertainty on these terms is related to the measurement precision

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- Uncertainty based on difference between nadir and 40 degrees for the following:
  - **Polarization Factors**
  - **OBC BB Emissivity**
  - **Nonlinearity**
- **Scan Mirror Temperature**: 5K worst case uncertainty estimated
- **Scan Mirror Angle**: Precision 14 bit encoder results in negligible error
- **OBC Temperature**: Technically related to precision < 10 mK, but we use what we can account for: 30 mK
- **Low Frequency Drift**: Measured by Space View Noise Test
- **LABB Temperature**: 27 mK (Bomem User Guide)
- **LABB Emissivity**: 0.0001 – 3 x (1-Emissivity)
- **Spectrometer Phase**: Zero
- **OBC BB Emissivity EOL:** Calculated by Analysis: 0.0002
- **OBC BB Reflected**: 1-Emissivity @ T_{sm} (Cavity)
- **Gain Drift**: Zero

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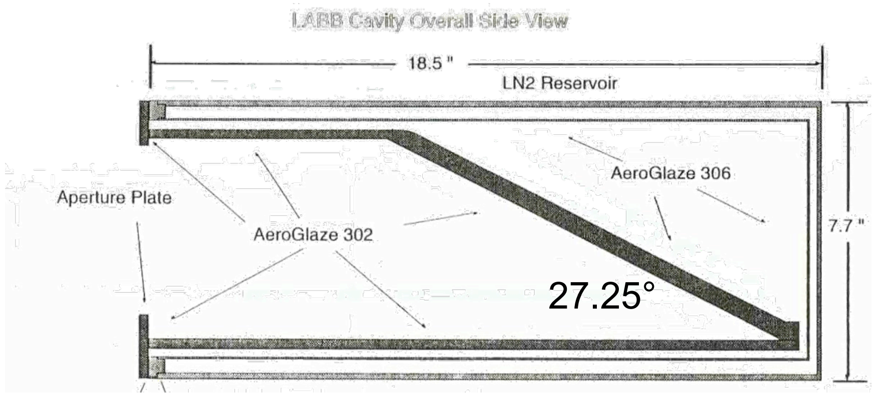
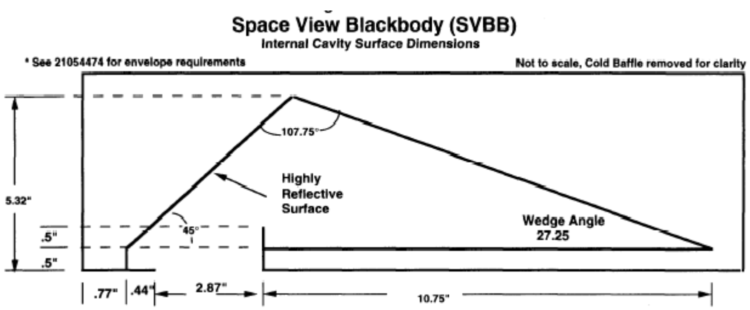
NIST Traceable External Large Area Blackbody (LABB) and Space View (SVBB)



- Large Area Blackbody (LABB)
- T = 190K to 360K
- $\varepsilon > 0.99998$
- NIST Traceable PRTs (Rosemont)
- T_precision = 0.01K
- T_accuracy = 0.027K



- Space View Blackbody (SVBB)
- T < 80 K
- $\varepsilon > 0.99998$
- T_precision = 0.01K
- T_accuracy = 0.5K

- AIRS Space View Blackbody and Large Area Blackbody (SVBB & LABB) User's Manual, Bomem, AI-BOM-022/96 Revision A, 14 August 1996

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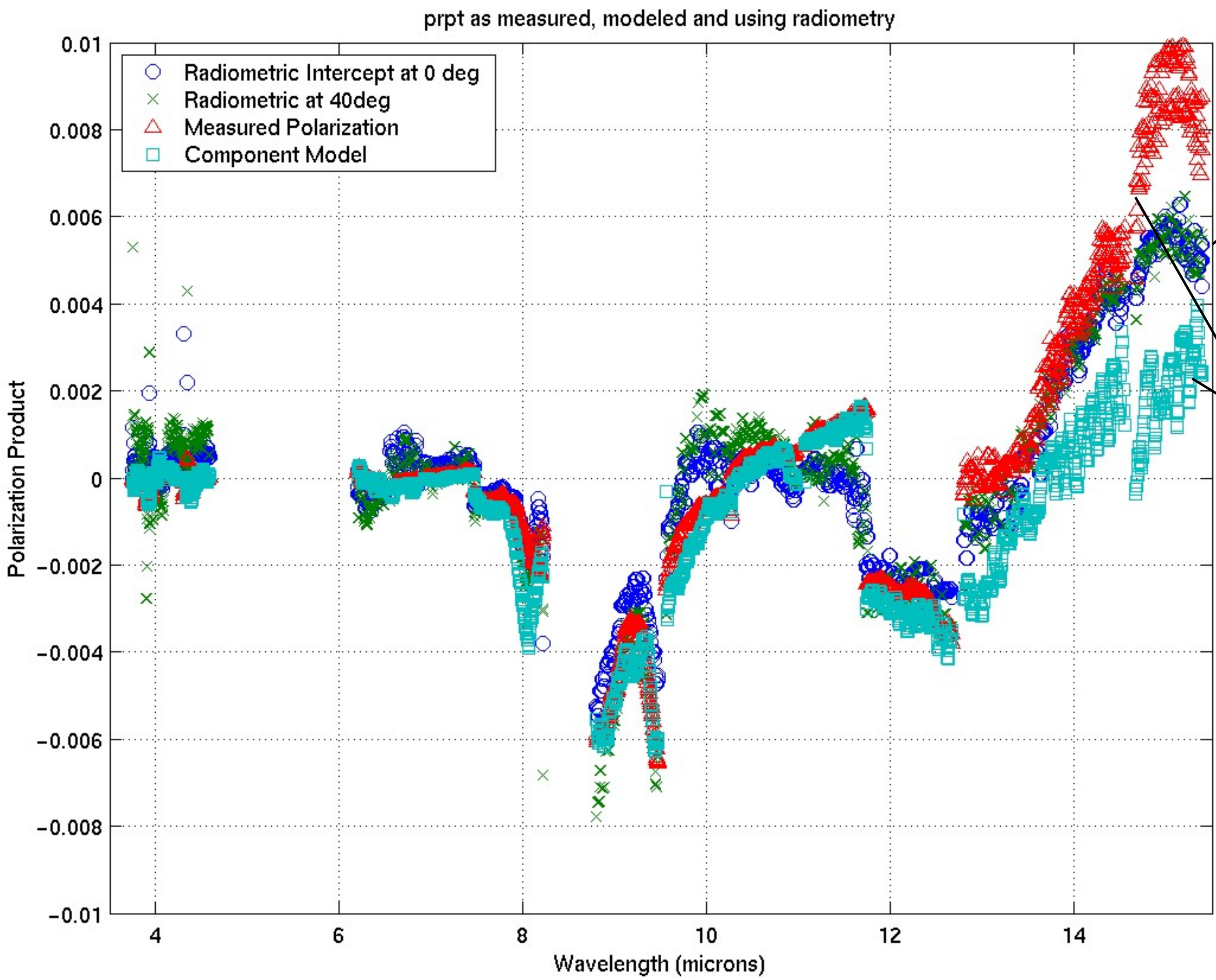
Multiple Sources for Polarization Data. V6 Uses Radiometric intercept at Nadir



Proposal for V6 uses $p_r p_t$ derived from radiometric intercept, a_o

V5 Used average of Measured and Component Model

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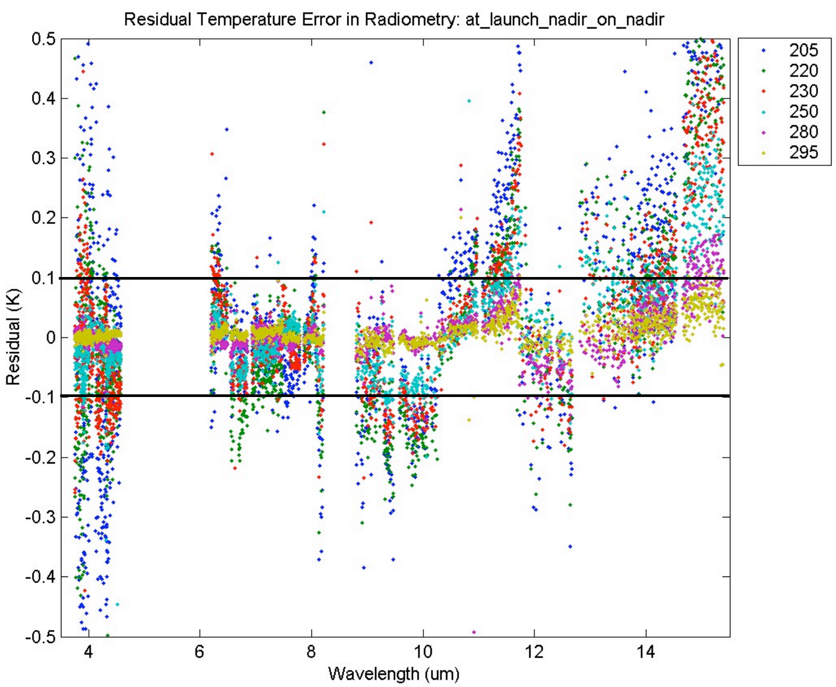
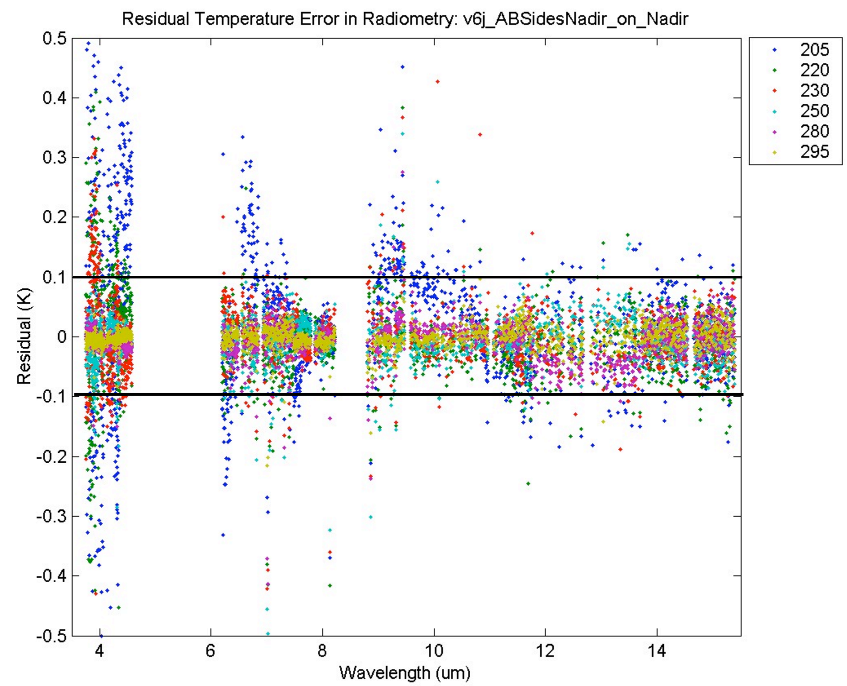
Precision in V5 Had Issues at Cold Temps. Proposed V6 Improvement Better

Version 5 (Nadir)

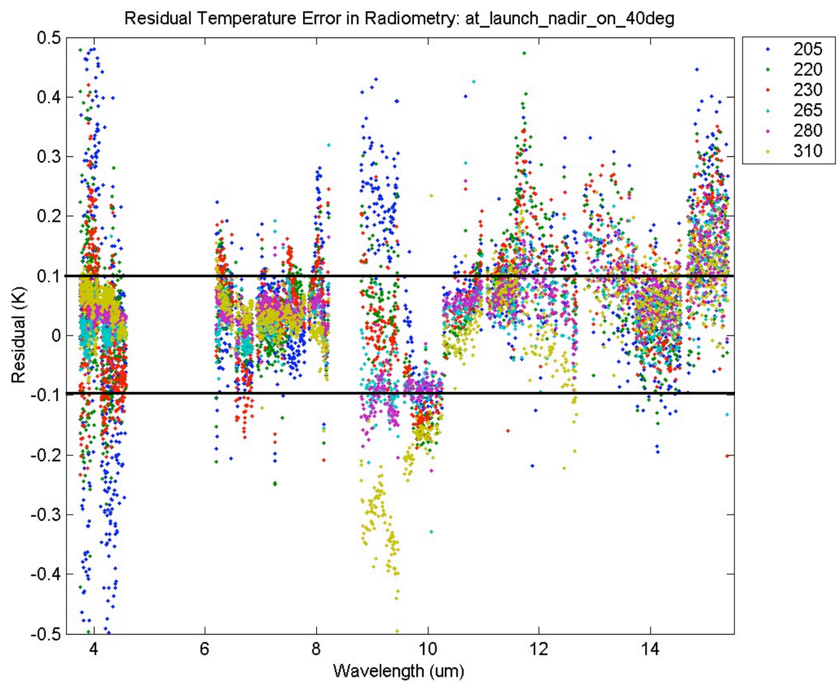


Version 6 Proposed(v6j) (Nadir)

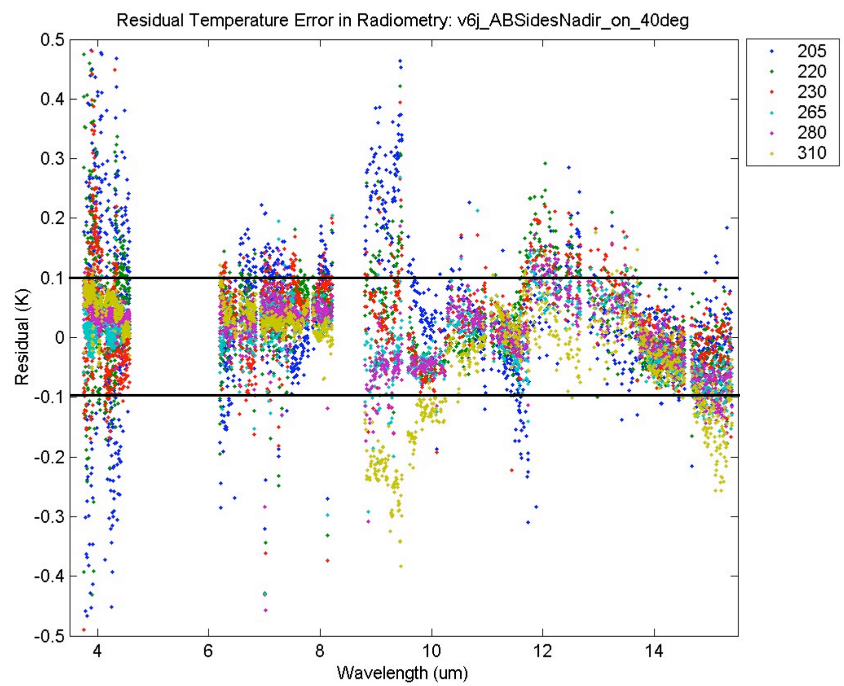


Measured Precision Lower at 40 Degrees

Version 5
(40 degrees)



Version 6 Proposed(v6j)
(40 Degrees)



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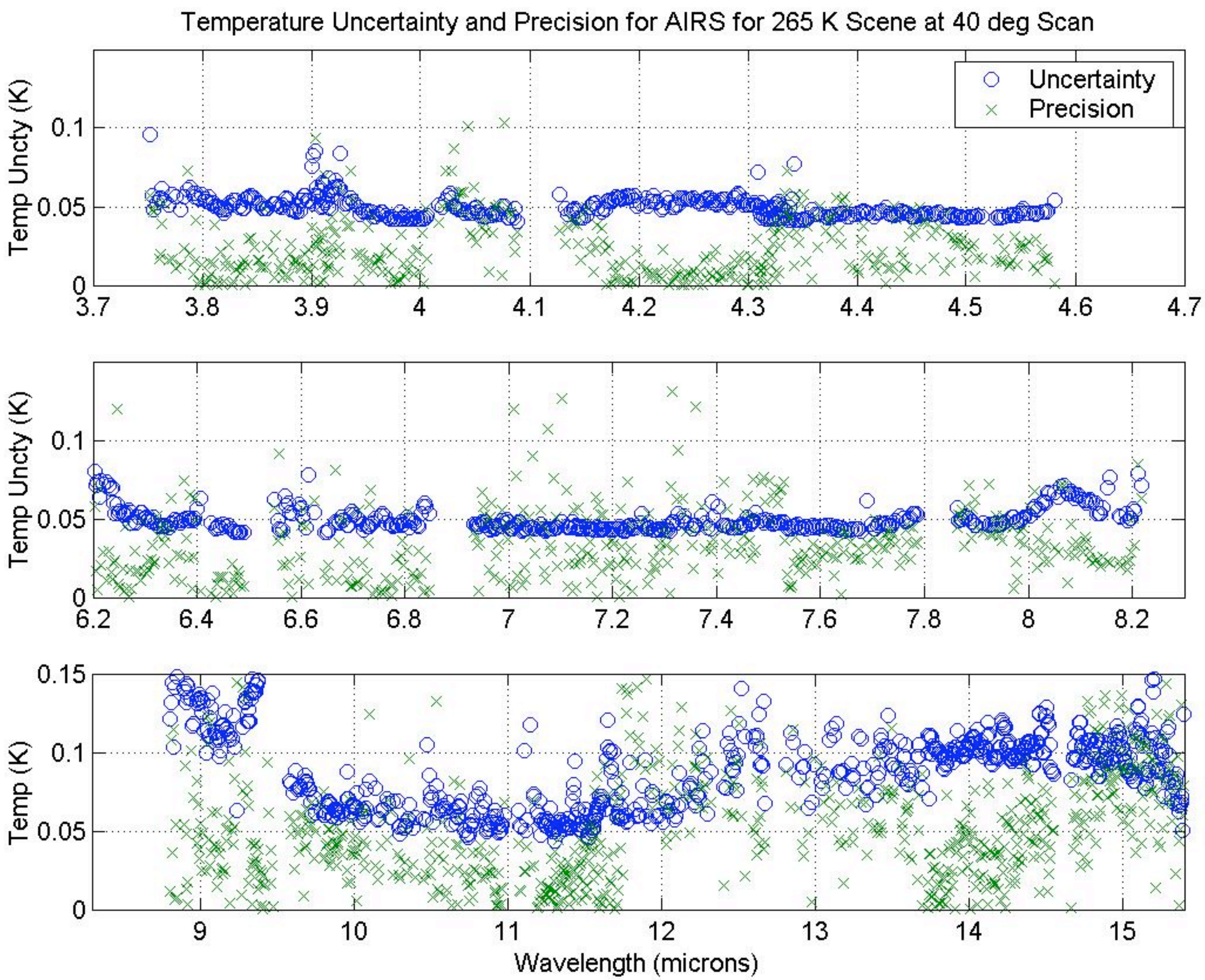
Channel Dependent Model Uncertainty (All Angles) and Measured Precision (40 degrees)



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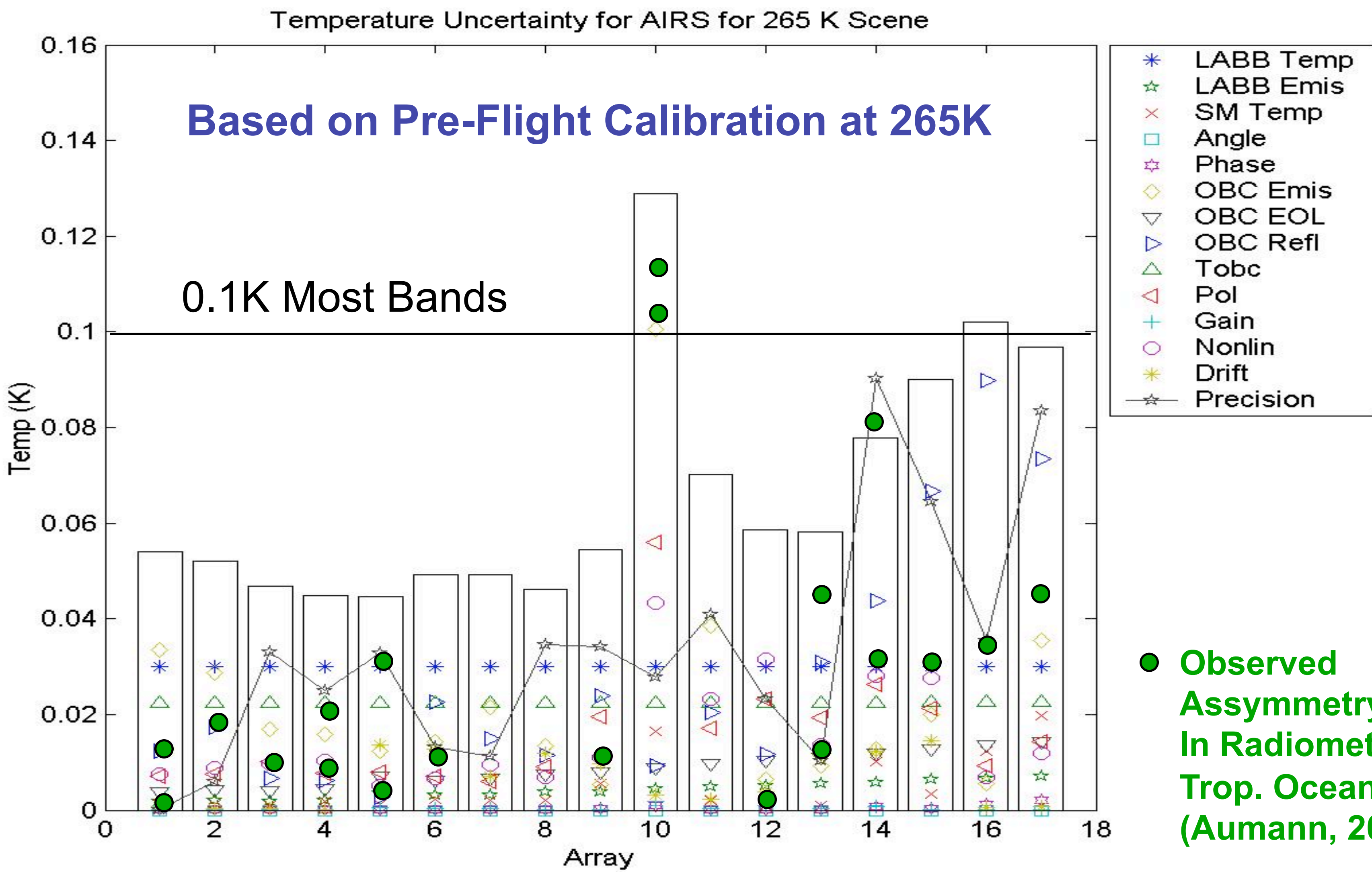
Look at Errors by Array

Table 1. Module Spectral Regions

Array	Module	Wavelength (min) (µm)	Wavelength (max) (µm)
1	M1a	3.7364	3.9169
2	M1b	4.11	4.3291
3	M2a	3.9149	4.11
4	M2b	4.3271	4.6085
5	M3	6.9356	7.4769
6	M4a	6.2003	6.4934
7	M4b	6.5504	6.85
8	M4c	7.4745	7.7921
9	M4d	7.8605	8.22
10	M5	8.8073	9.4796
11	M6	9.565	10.275
12	M7	10.275	10.985
13	M8	11.0704	11.7512
14	M9	11.7431	12.685
15	M10	12.7989	13.7457
16	M11	13.7377	14.5533
17	M12	14.6672	15.4

Radiometric Uncertainty Estimate at 265K



● **Observed Assymmetry In Radiometry Trop. Oceans (Aumann, 2008)**

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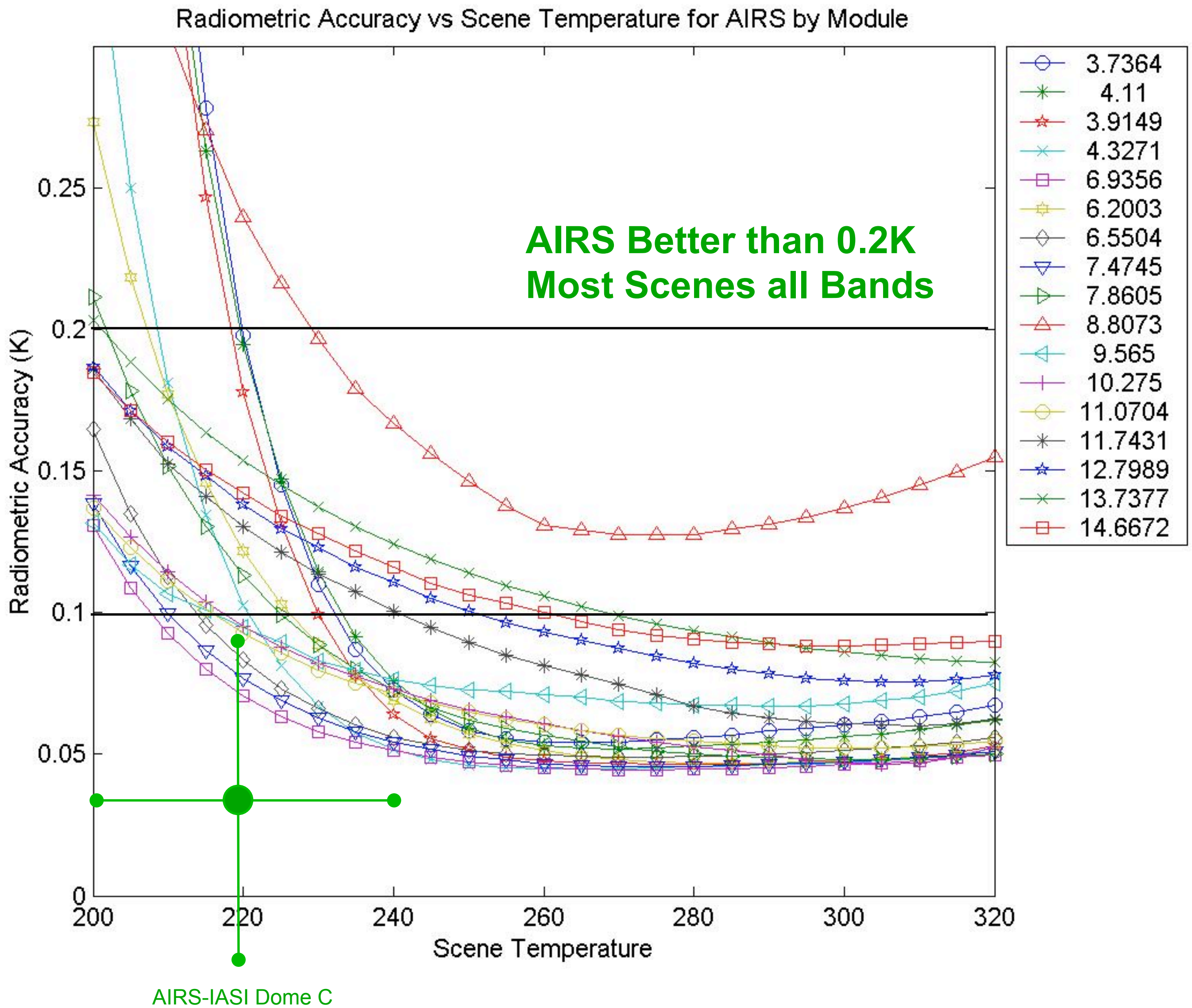
Modeled Temperature Dependence of Radiometric Errors



Summary and Conclusions

- AIRS Instrument Designed for High Sensitivity, Accuracy and Stability
- Radiometric Calibration tied to NIST Sensors in LABB
- Uncertainties Quantified for all Terms
- Precision Measured at Nadir and 40 Degrees
- New Polarization Coefficients based on radiometric intercept will improve precision at nadir
- Uncertainties less than 0.6K (1 sigma) at 265K, Estimate on average AIRS better than 0.2K 3 sigma. Expect Uncertainty < 0.3K 3σ with margin.
- Temperature dependence modeled
- Future work
  - Improve AB dependence on coefficients
  - Look for additional error sources
  - Improve selection of test data used in the calibration
  - Verify improvement in PGE
  - Decide whether valuable for Version 6
  - Reprocess
- AIRS Calibration Accuracy can improve within the limitations of our pre-flight test program.
- Do we include in-flight observations at some point?